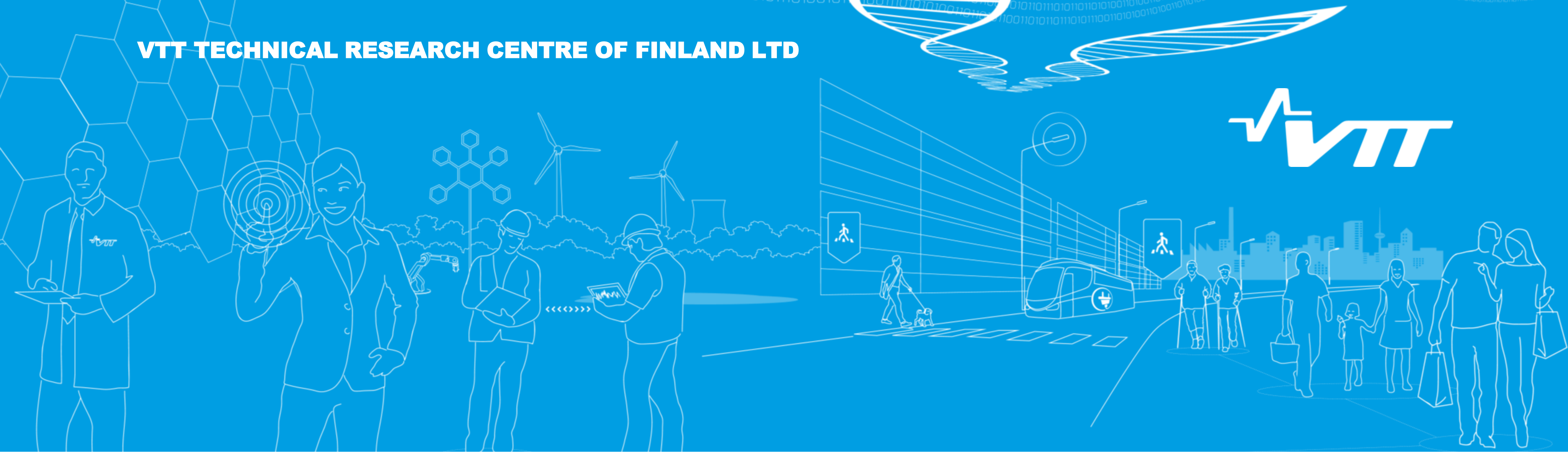

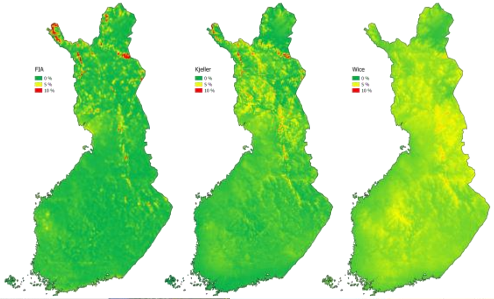

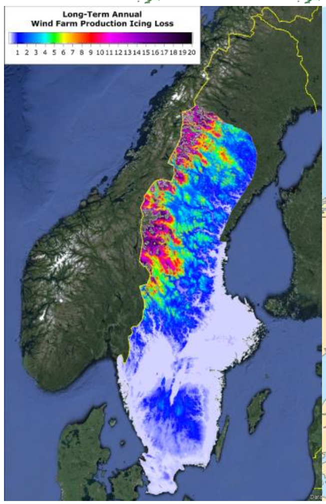

Validation of Icing atlases using SCADA data

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Winterwind 2016,
Åre, Sweden

Aim

- Compare existing ice maps to on-site measurements
- Use SCADA data from actual, operating wind turbines as ice detectors for validation
- Evaluate how well icing atlases can be used in icing assesment

Ice maps

VENDOR	MEASURE	SOURCE	AREA
FMI	Meteorological, instrumental, production losses	Numerical weather model	Finland
Kjeller Vindteknik	Meteorological icing	Numerical weather model	Finland, Sweden
VTT	Meteorological icing	Observations	Finland, Sweden (Global)
DNV-GL	Instrumental icing, Production losses,	Observations	Sweden
Weathertec Scandinavia	Meteorological icing, Production losses	Numerical weather model	Sweden, Finland

Long term outlook

- Two of the datasources contain a longer dataset
  - 1979-2015
- This allows us to estimate how the years with measurements stack up to history
- Compare the years with measurements to historical averages
- See how much icing fluctuates on either site

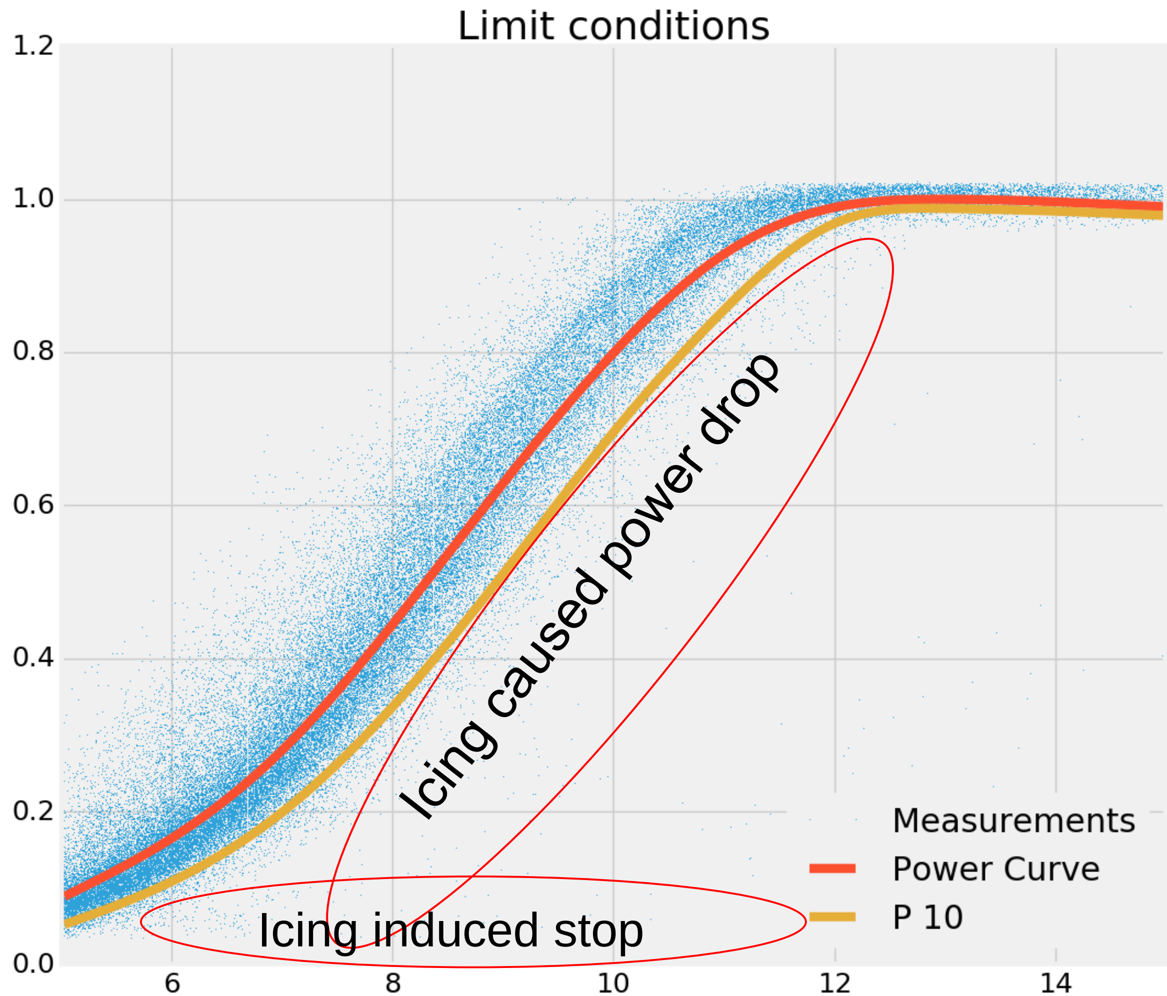
Turbine icing

- Calculated using method published by IEA wind task 19
- Indirect
- Observe effects on turbine performance
- Power decrease from nominal
- Inexplicable stops
- Rotor icing

https://www.ieawind.org/task_19/Task19 Ice Loss Method.html

Ice case definition

- Output power outside of P10 of normal operation in safe conditions for +30 minutes
- Icing induced stop
- Outputs:
  - Production losses
  - Rotor icing (amount of hours turbine is effected by icing)



Ice classification

- Different sources measure different things
  - Meteorological or rotor icing, production losses
- Need common ground for comparison
- IEA ice classes used a quite often
  - Same ice class -> good enough accuracy

Ice classes: IEA Ice Classification[1]

IEA ice class	Duration of Meteorological icing [% of year]	Duration of Instrumental icing [% of year]	Production loss [% of AEP]
5	>10	>20	>20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0-0.5

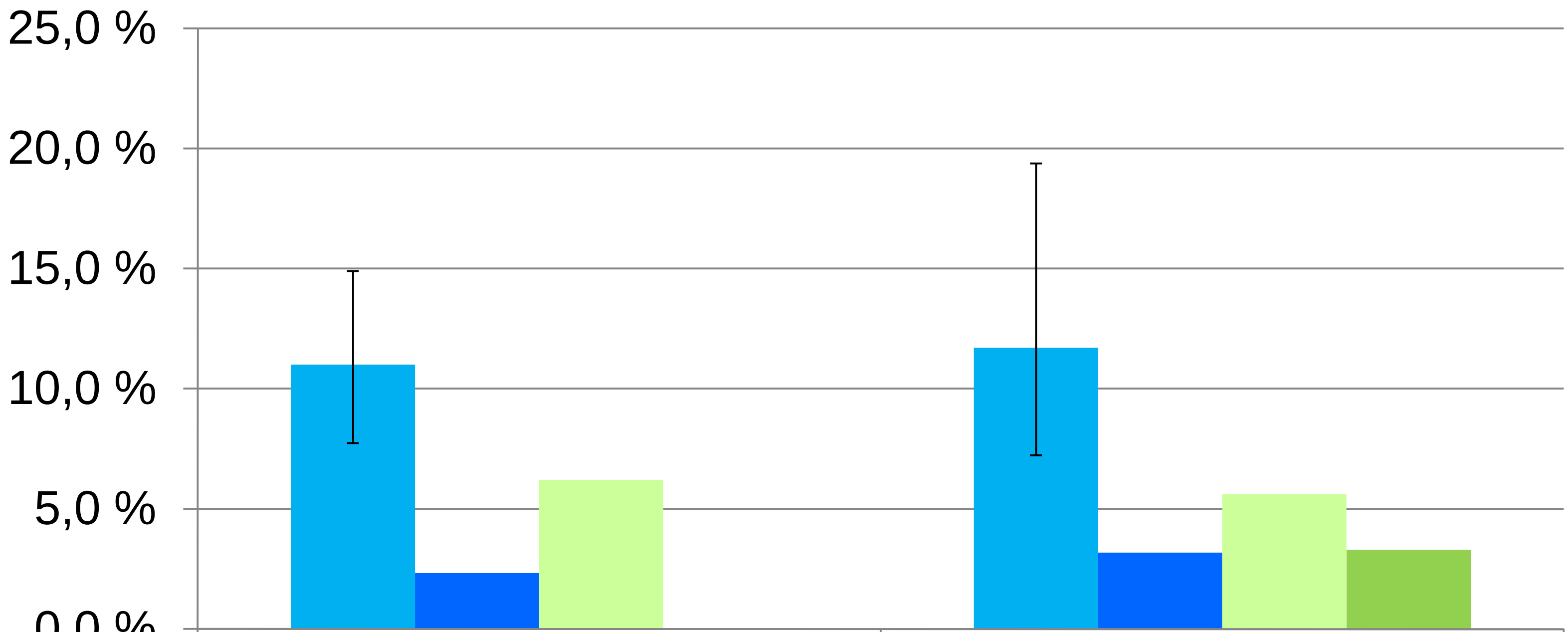
[1]: IEA Wind Recommended Practices for wind energy projects in cold climates edition 2011, Task 19

Sites

- Site SWE
  - In Northern Sweden
  - Multiple turbines
  - Relatively bad icing conditions
  - Only turbines, no external measurements
- Site FIN
  - Finnish developer with portfolio of several farms
  - Several projects in pipeline
  - Case wind farm:
    - Turbines A & B (3MW, HH140m, D120m)
    - A & B close to each other
  - Ice detector on site
  - Heated + non-heated anemometers

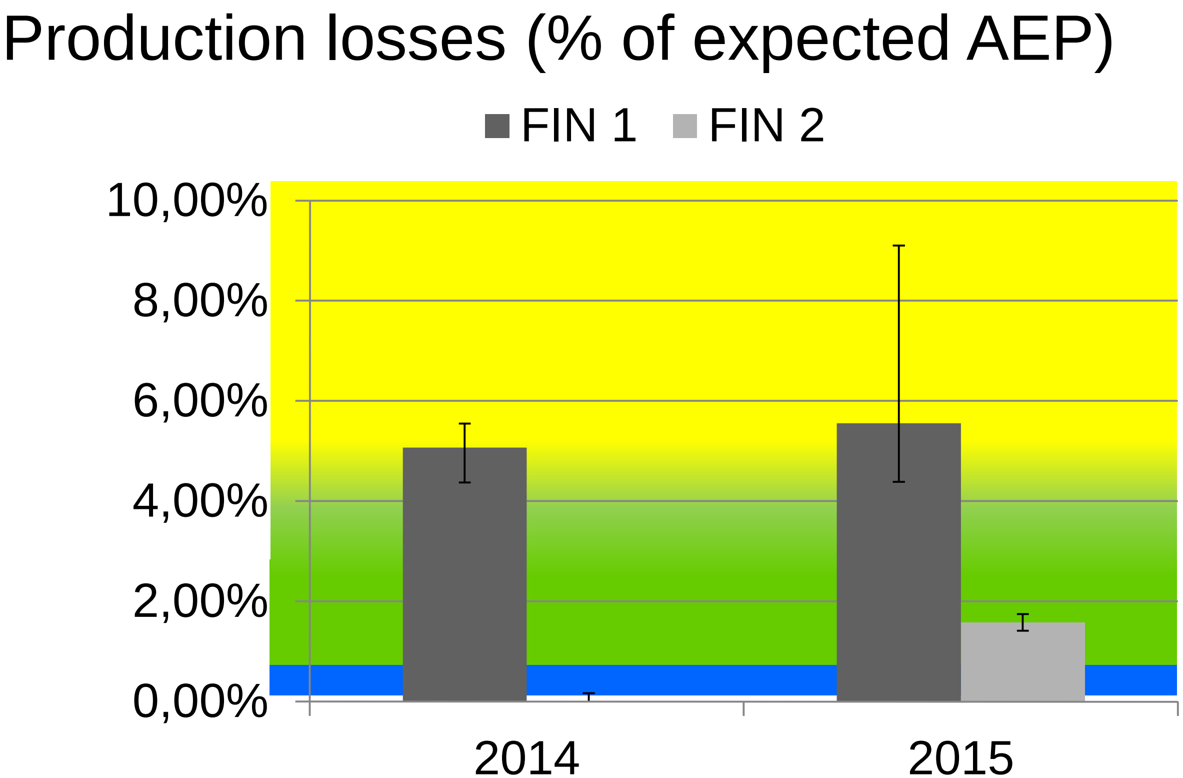
SCADA Data and instruments, Site FIN

Icing hours (% of annual)



	2 014	2 015
Instrumental icing	11,0 %	11,7 %
Ice detector	2,3 %	3,2 %
Rotor Icing FIN 1	6,2 %	5,6 %
Rotor icing FIN 2	0,0 %	3,3 %

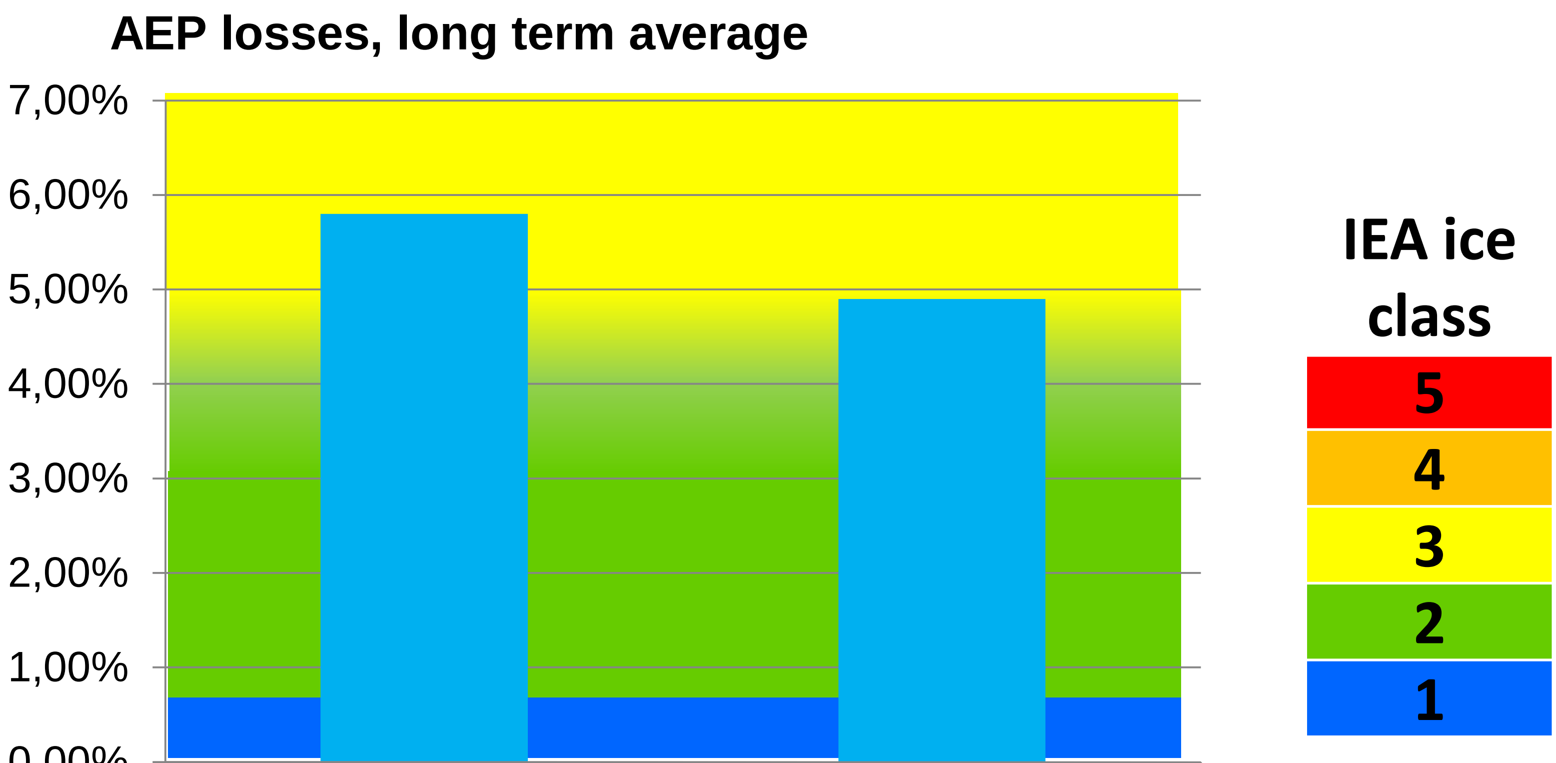
SCADA Production losses



- Large differences between two turbine types
- Installed close to each other on similar terrain

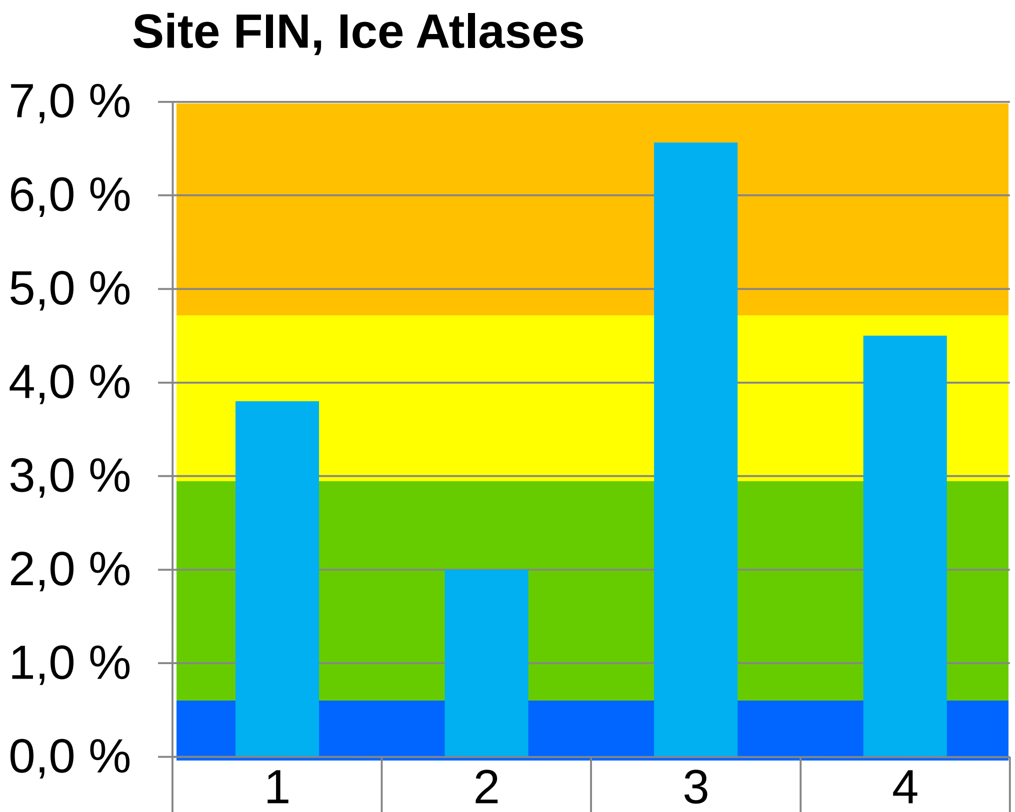
IEA ice class
5
4
3
2
1

Icing Atlases, site FIN

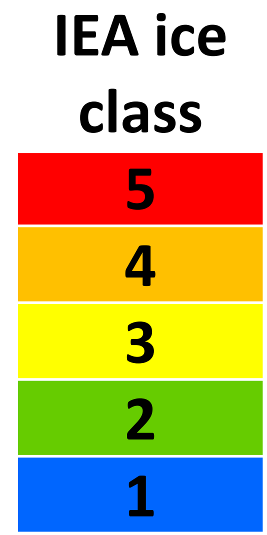


	1	2
AEP losses, long term average	5,80%	4,90%

Icing atlases, site FIN



	1	2	3	4
Meteorological icing, long-term average	3,8 %	2,0 %	6,56%	4,5 %



Historical outlook, site FIN

Annual meteoroligical icing (%)

	source 1	Source 2
Average	4.6 %	6.6 %
Min	2.2 %	4.4 %
Max	8.0 %	9.0 %

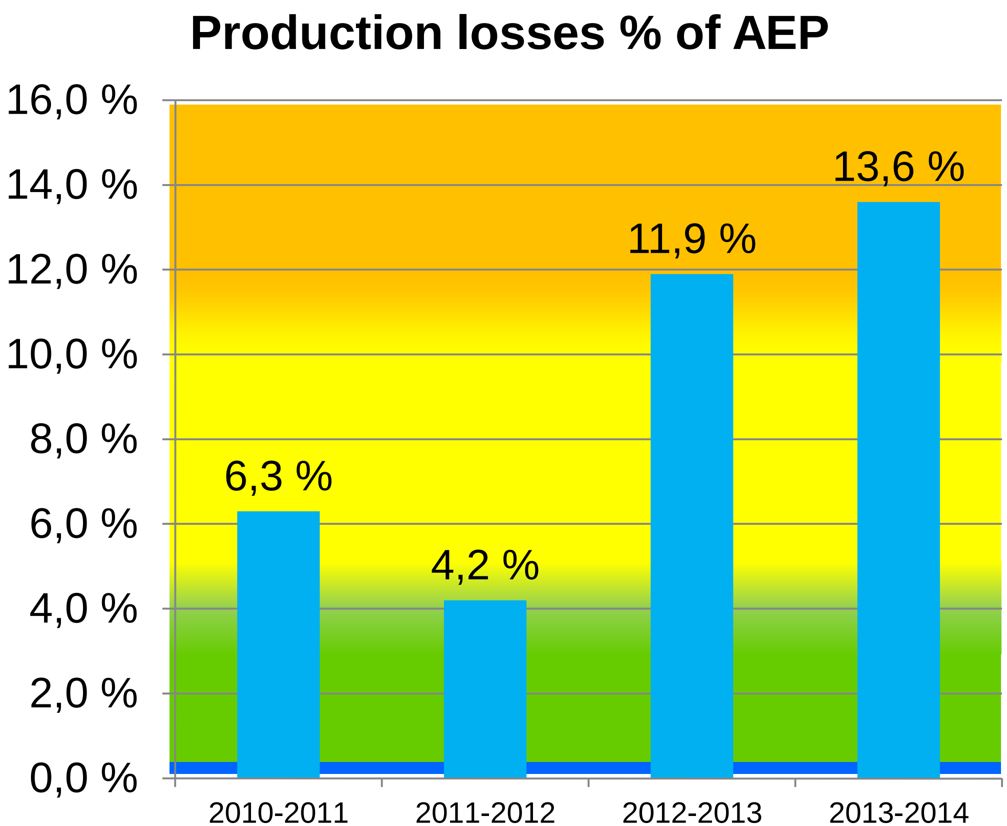
- 35 year datasets differ for the same site quite substantially
- This can be attributed to differences in methods to some degree
- Both records show large variance between the best and worst years
  - At most ~70%

IEA Classification, Site FIN

- Set an ice class from all data sources
  - 7 classifications based on ice atlases
  - 4 based on measurements
- Average ~3
- Icing atlases give higher estimates than measurements
- Different turbine brands behave differently in icing conditions

Source	Ice classes
Icing atlases, Meteorological icing	3, 4, 2, 3
Icing atlases, AEP loss	3, 3
Instruments	2, 2, 3
Production losses	2-3, 2

Results, site SWE



- Average loss 9%

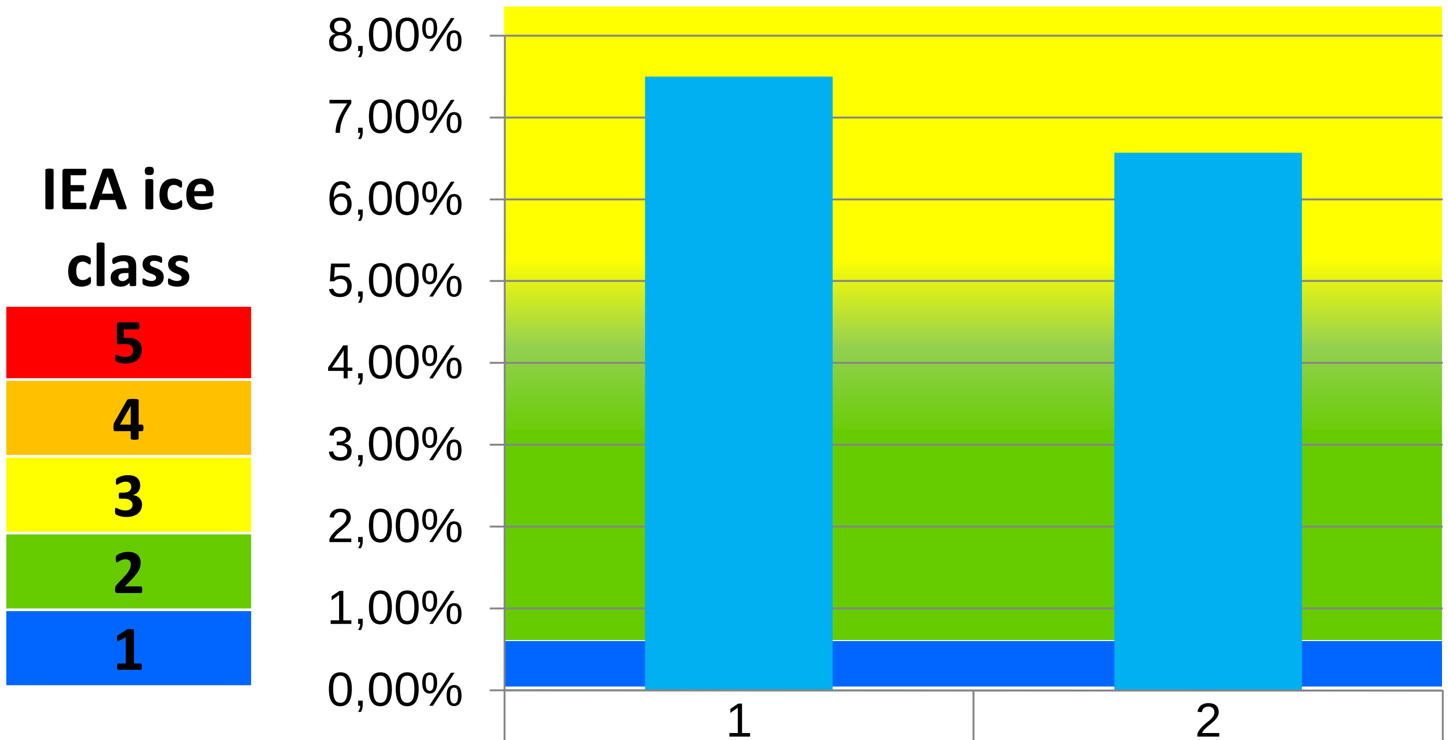
- Large year-over-year differences
  - 300% from min to max

IEA ice class

5
4
3
2
1

Ice atlases, site SWE

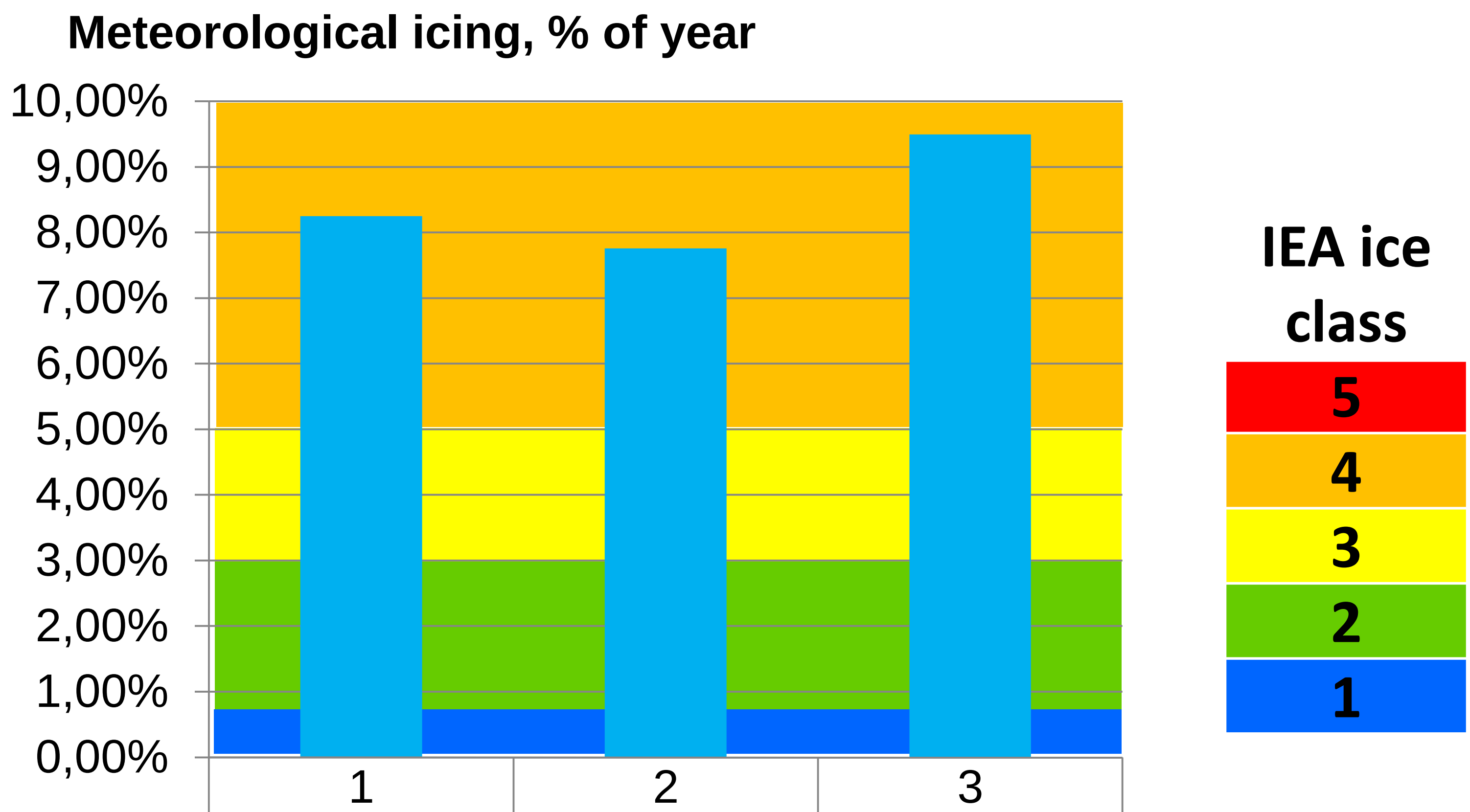
AEP losses, long term average



	1	2
AEP losses, long term average	7,50%	6,57%

Measured Average 9 %

Ice atlases, site SWE



	1	2	3
Meteorological icing, % of year	8,25%	7,76%	9,5 %

Ice classification site SWE

Source	Ice class
Turbine losses	3
Ice atlases, meteorological icing	4, 4, 4
Ice atlases, production losses	3, 3

- Here the difference is smaller
- Estimates of meteorological icing seem to overshoot the measurements as well
- Is this caused by the loss counting method?
  - Total losses more than what is accounted for icing here
  - Does the definition need re-visiting?

Historical outlook, site SWE

Annual metorological icing %

	Source 1	Source 2
average	9.5 %	6.0 %
min	6.7 %	3.9 %
max	13.5 %	9.9 %

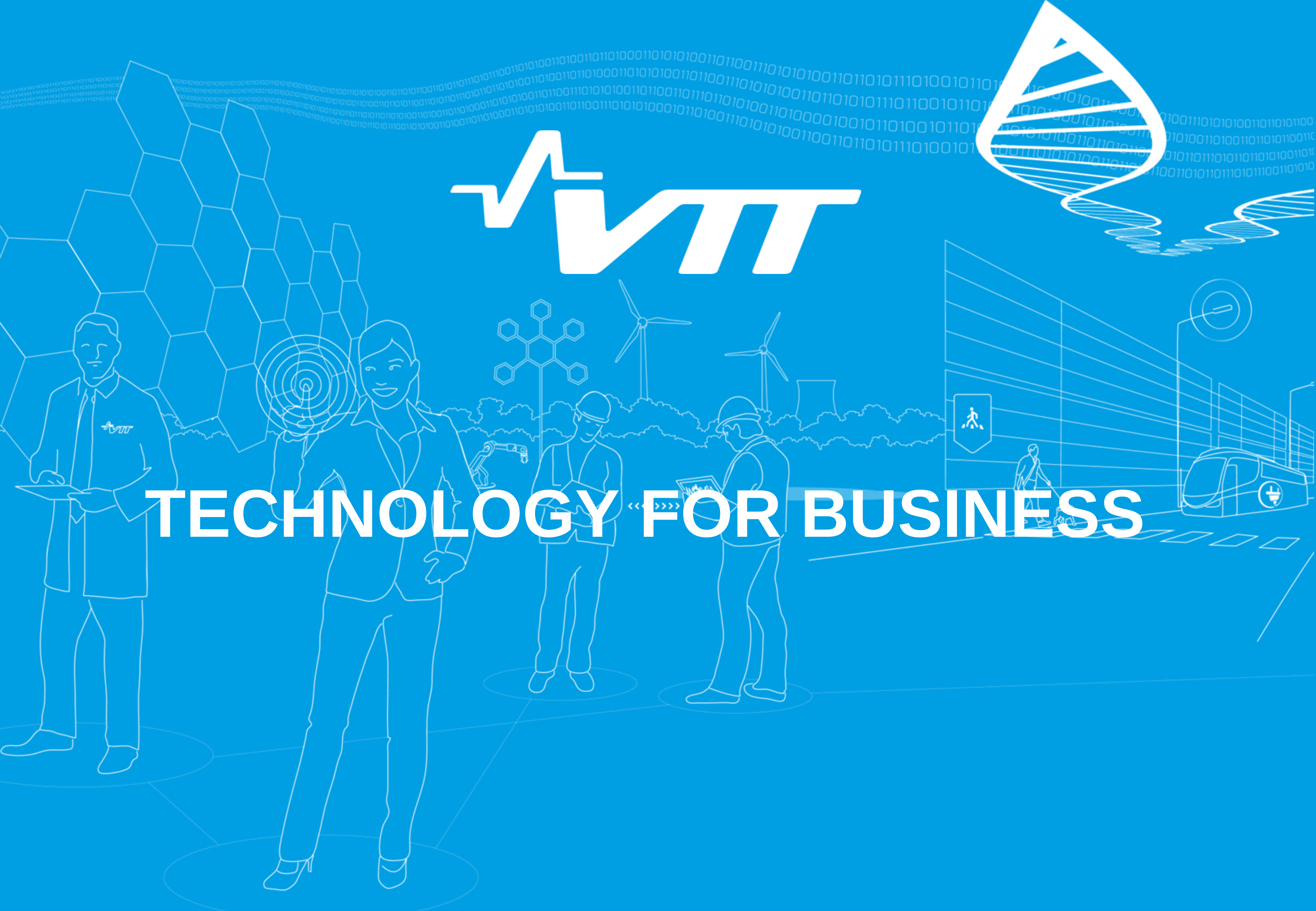
- Large difference between best and worst years
- Site ice class > 3
- Individual year results don’t correlate with measurements

Key takeaways

- IEA ice classification seems to work

- Good ice classification requires
  - Multiple sources
  - Multiple years of data

- Models and measuremeents agree only on long-term trends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